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ACTIVE TESTING SURVEILLANCE SYSTEMS, OR, PLAYING TWENTY QUESTIONS WITH A RADAR

Daniel R. Fuhrmann

Department of Electrical Engineering

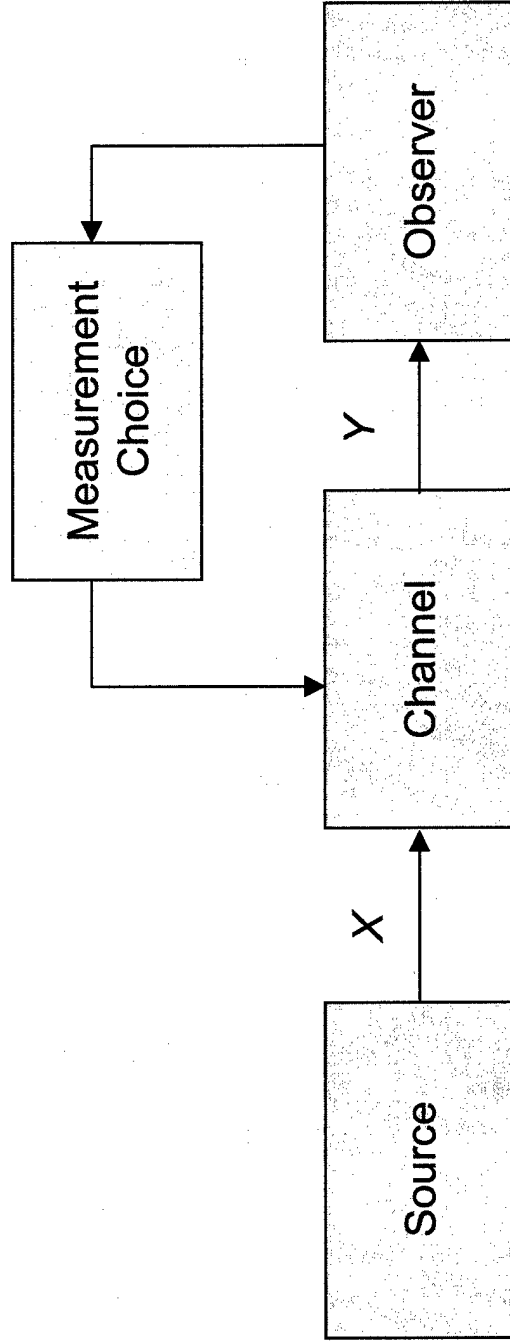Washington University in St. Louis

CONTEXT

- Airborne multisensor pulse-Doppler surveillance radar

- Ground moving targets (GMTI)

- Multiple targets

- Geographical side information (GIS)

- Platform side information (GPS, INS)

CONTEXT
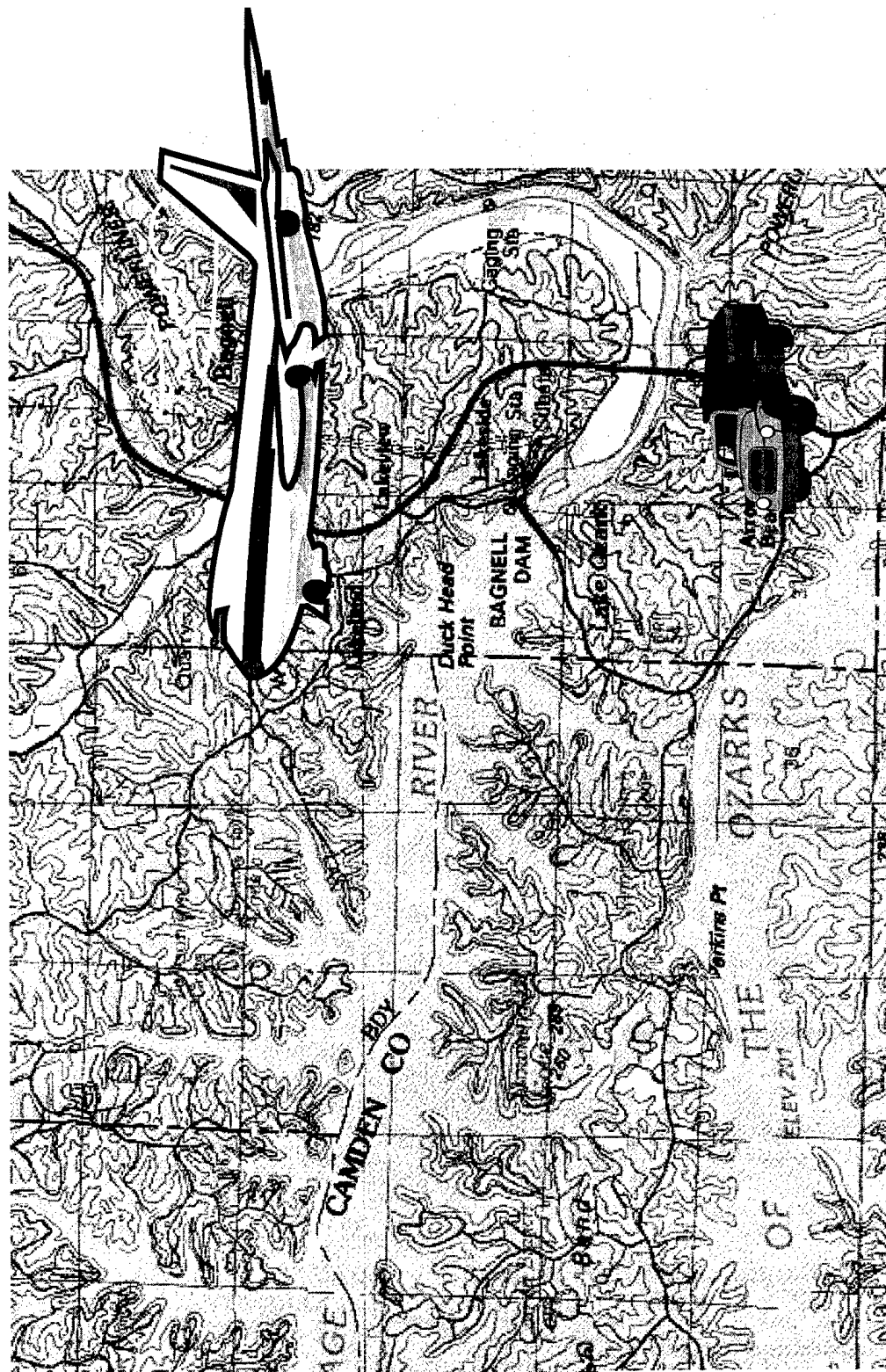
ACTIVE-TESTING SURVEILLANCE SYSTEM

A communication system in the usual information-theoretic sense, with the added feature that the channel can be manipulated by the observer.

GENERAL APPROACH

The goal of a surveillance system is to minimize the entropy of the posterior distribution of the source vector X.

- Entropy definition:

$$H(X) = -\sum_x p_X(x) \log_2 p_X(x)$$

- Conditional entropy definition:

$$H(X|Y) = -\sum_y p_Y(y) \sum_x p_{X|Y}(x|y) \log p_{X|Y}(x|y)$$

$$= -\sum_y \sum_x p_{XY}(x,y) \log p_{X|Y}(x|y)$$

SINGLE-MEASUREMENT STRATEGY

Choose that measurement which maximizes the mutual information I(X,Y)

• Mutual information definition:

$$I(X,Y) = H(X) - H(X|Y)$$
$$= H(Y) - H(Y|X)$$

Repeated measurements: maximizing $I(X,Y)$ at each step seems obvious and intuitive, but is "greedy" and may not be globally optimal.

TWENTY QUESTIONS

- A game in which the objective is to determine the correct answer by asking the right questions in the right order.

- Perhaps "Battleship" or "Mastermind" is a better analogy, since there is more feedback from observation to question.

- Connection with source coding: in binary coding, each bit represents the answer to a YES/NO set membership question. We like each bit to be maximally informative. If the bits are determined sequentially this is like Shannon-Fano coding. The globally optimum code is the Huffman code.

SAMPLING OF RELEVANT LITERATURE

- Sequential detection: Berger (1980)

- Experimental design: Carlin and Louis (1996)

- Coding theory connection: Goodman and Smyth (1988)
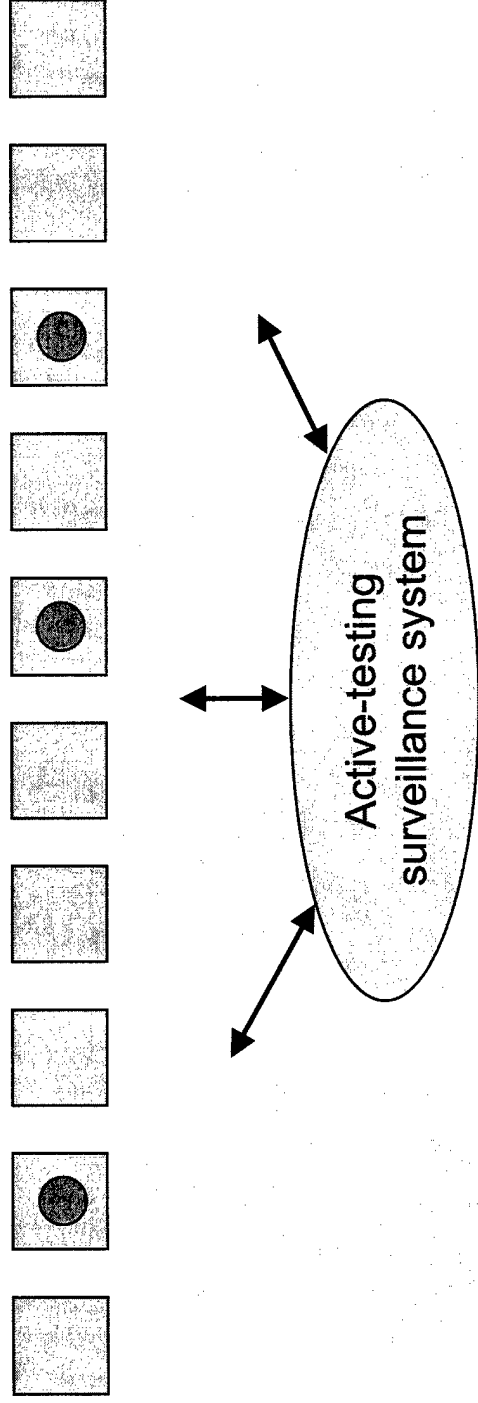
- Selection of maximally informative measurement:

    Lewis (1962)
    Pearl (1988)
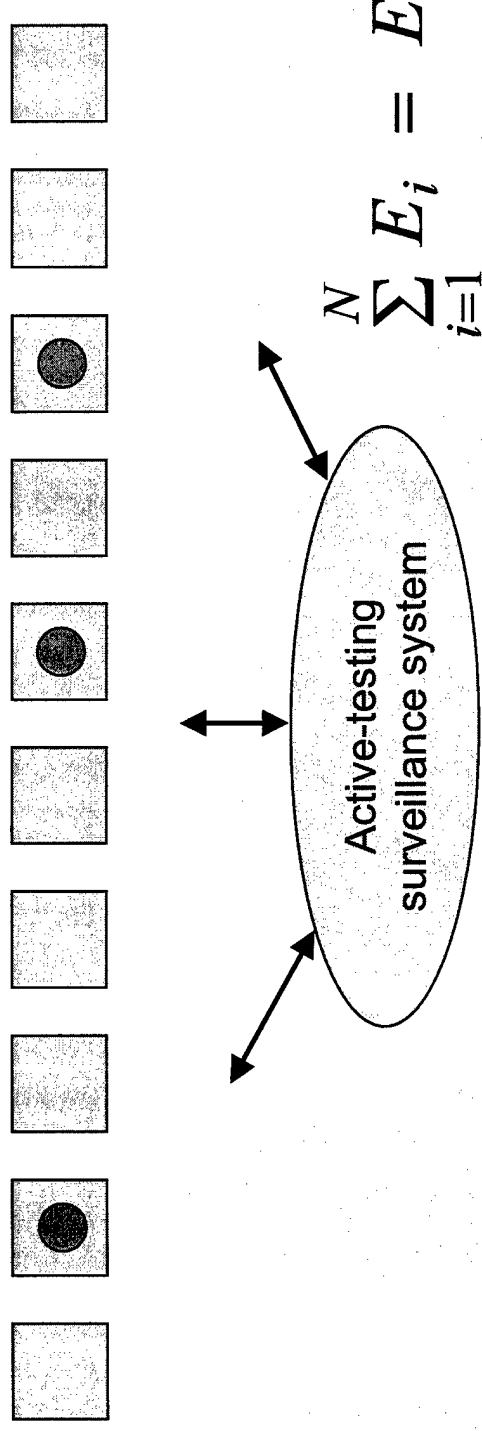   Geman and Jedynak (1996)
    Yuille and Coughlan (2000)

MULTIPLE TARGET DETECTION SCENARIO

Active-testing surveillance system

- N independent cells

- Each cell defines a binary hypothesis testing problem

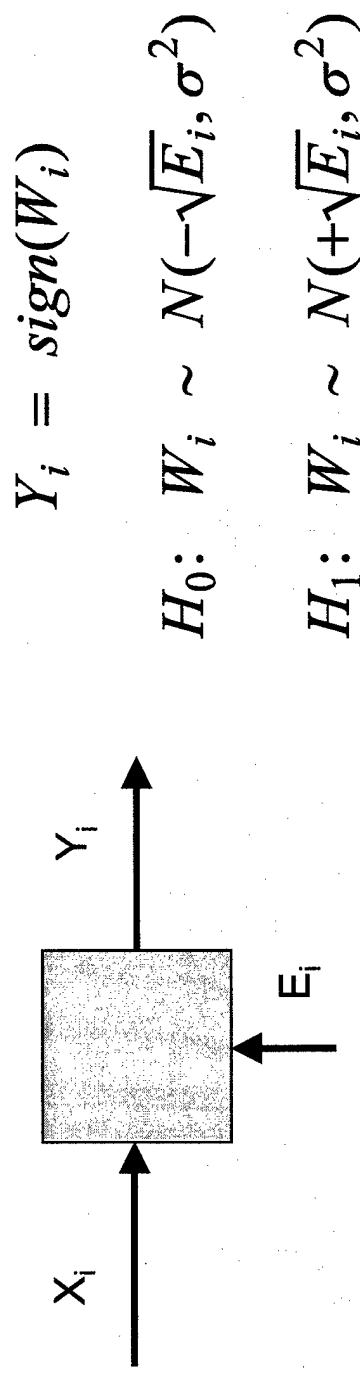- Divergence between H0 and H1 depends on transmitted energy

FINITE-ENERGY CONSTRAINT

Active-testing surveillance system

$$\sum_{i=1}^{N} E_i = E$$

- What is the optimum partition of the available energy E?

SIMPLE DATA MODEL

- Each cell acts like a binary symmetric channel (BSC):

$$Y_i = sign(W_i)$$

$$H_0: \quad W_i \sim N(-\sqrt{E_i}, \sigma^2)$$

$$H_1: \quad W_i \sim N(+\sqrt{E_i}, \sigma^2)$$

X_i Y_i

E_i

$$P_{e,i} = 1 - \Phi\left(\frac{\sqrt{E_i}}{\sigma}\right)$$

FAMILY OF I(X,Y) vs. SNR CURVES

MUTUAL INFORMATION VS. SNR AND PRIOR PROBABILITY
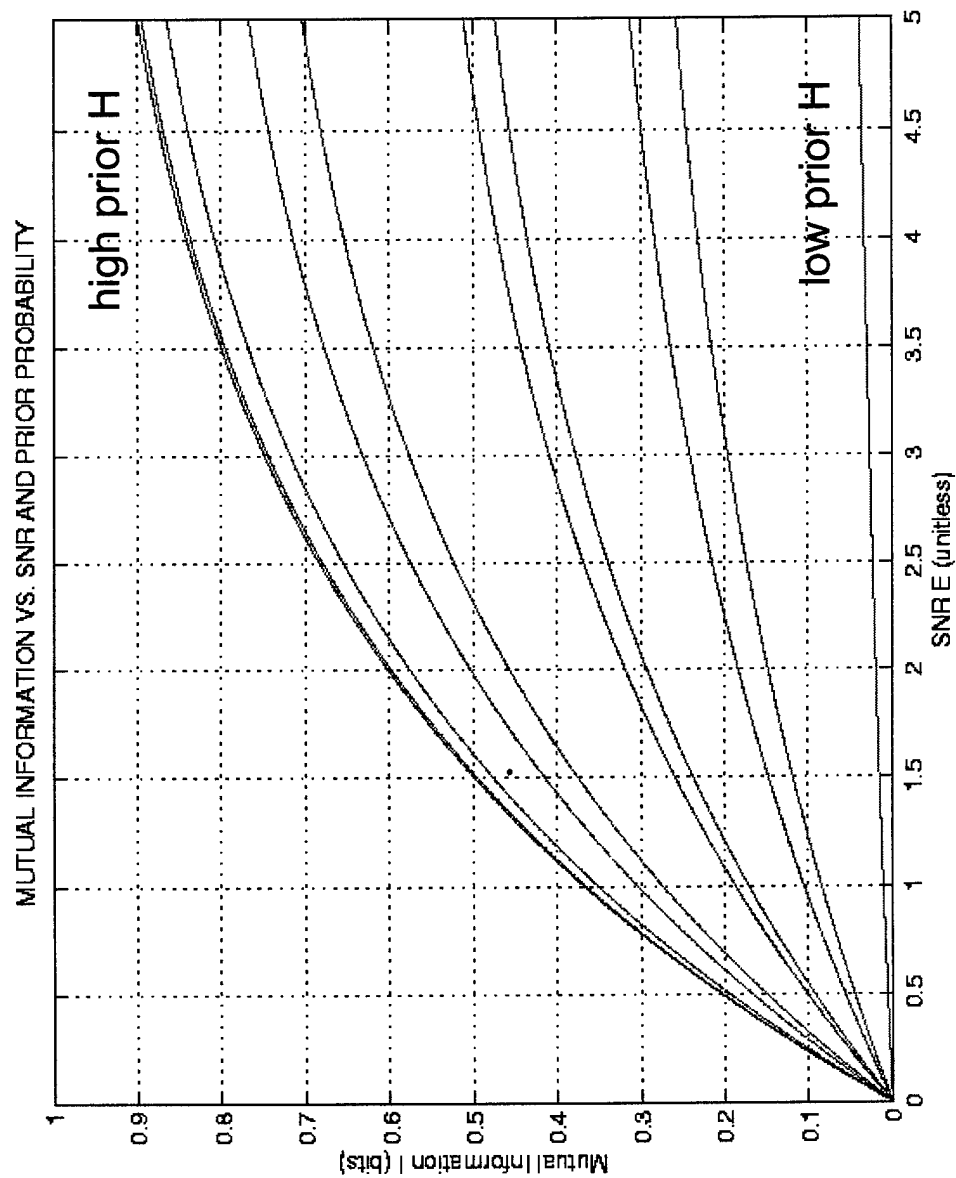
OPTIMIZATION OF ENERGY PARTITION

- Optimization problem:

$$\max_{\{E_i\}} \sum_{i=1}^{N} I(X_i, Y_i; p_i, E_i) \quad s.t. \quad \sum_{i=1}^{N} E_i = E$$
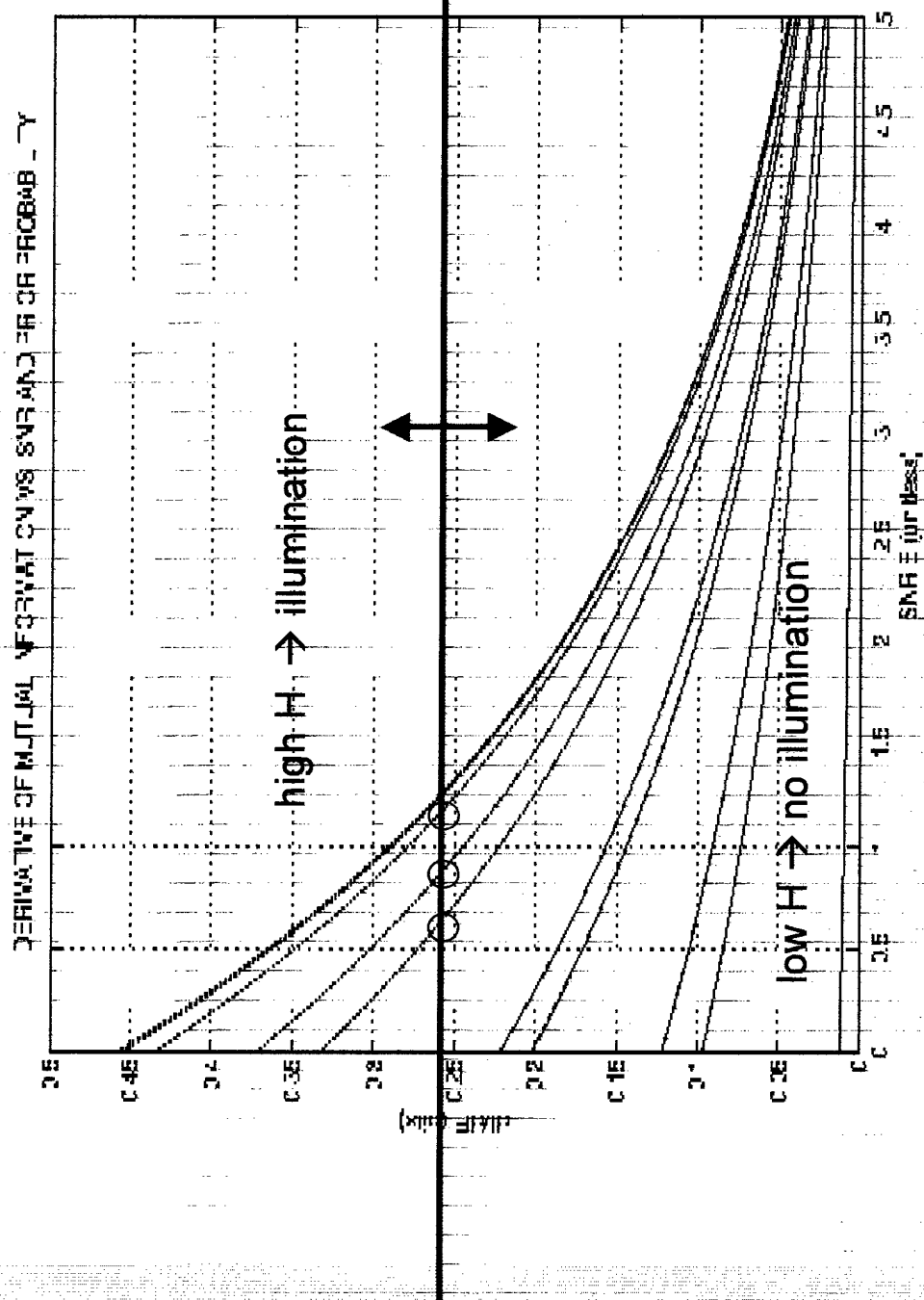
- Kuhn–Tucker conditions:

If $E_i \neq 0$, then $\dfrac{\partial I}{\partial E_i} = \lambda$

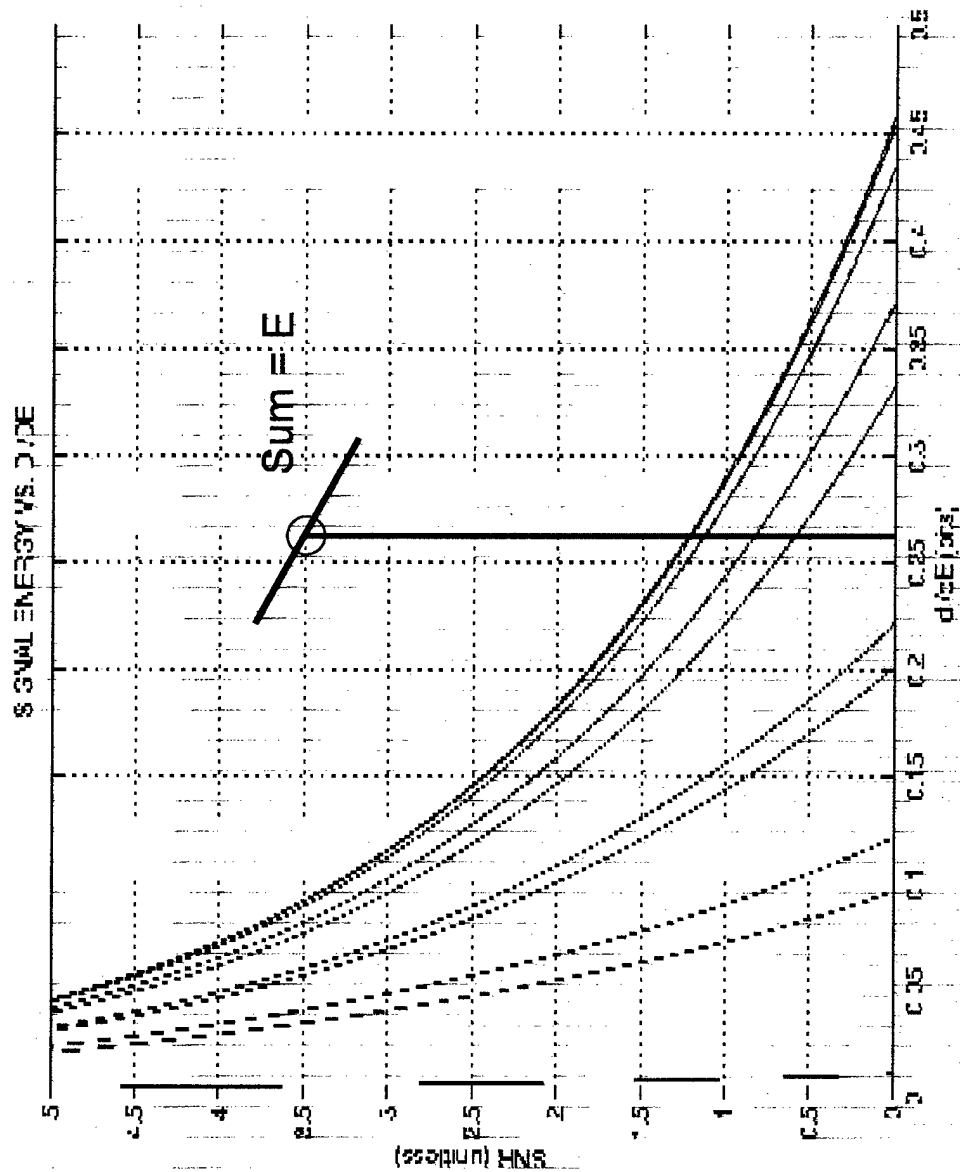If $\dfrac{\partial I}{\partial E_i} < \lambda$, then $E_i = 0$

FAMILY OF dI/dE CURVES

DERIVATIVE OF MUTUAL INFORMATION VS. SNR AND PRIOR PROBABILITY
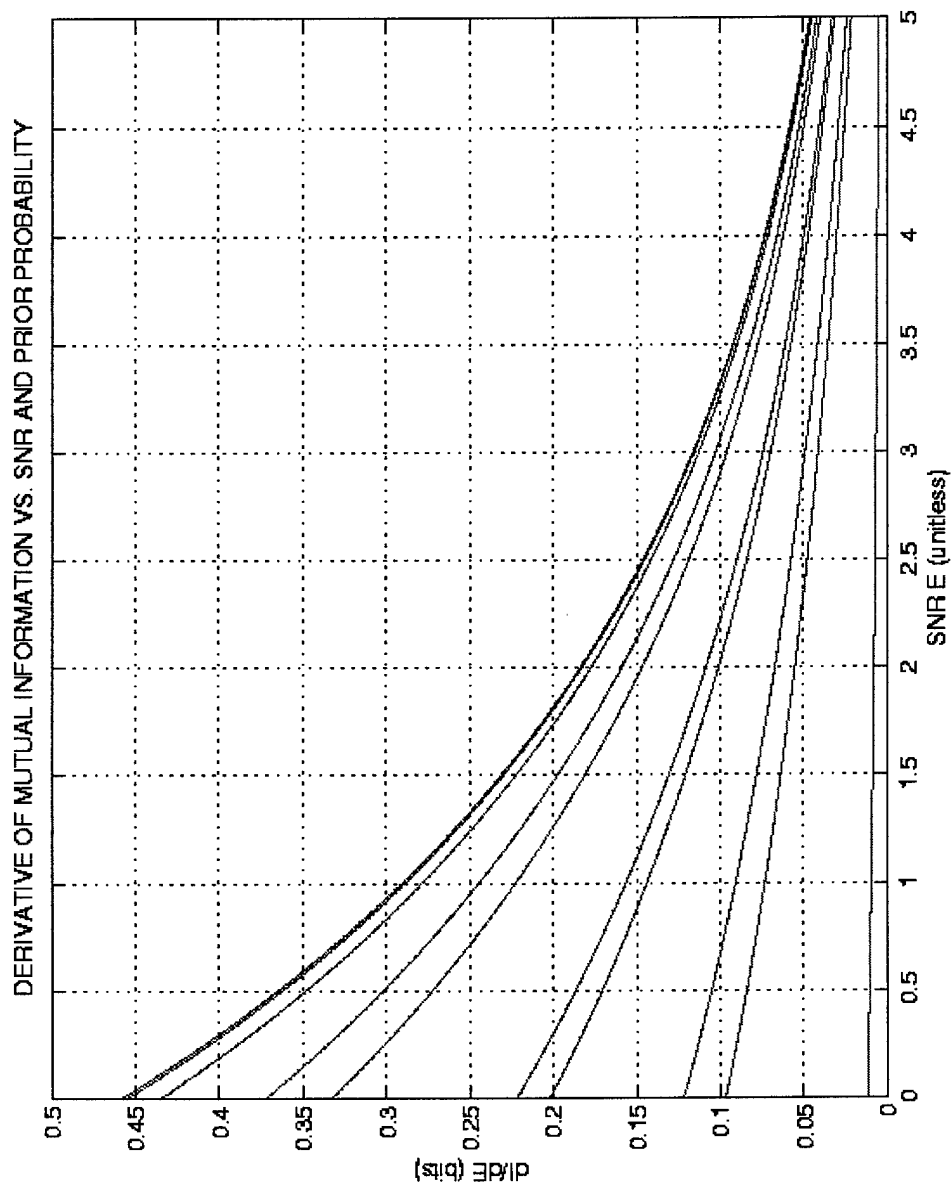
FINDING THE OPTIMAL PARTITION

OPTIMAL PARTITION (ALTERNATE VIEW)

SIGNAL ENERGY vs. D/DE

Sum = E

SNR (unitless)

d/dE|SR|
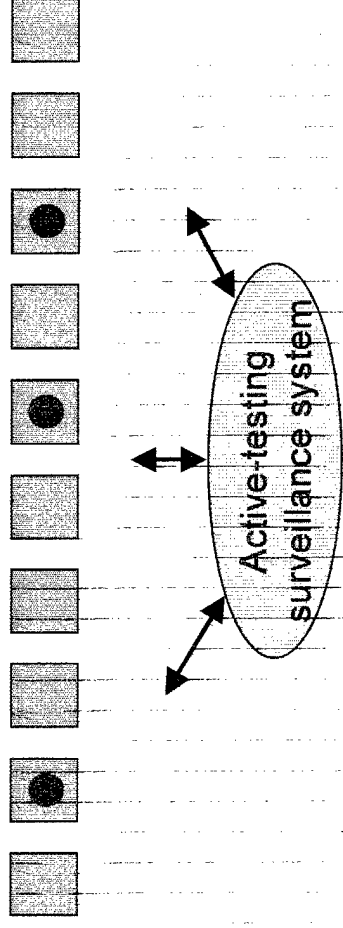
ACTIVE TESTING, AGAIN

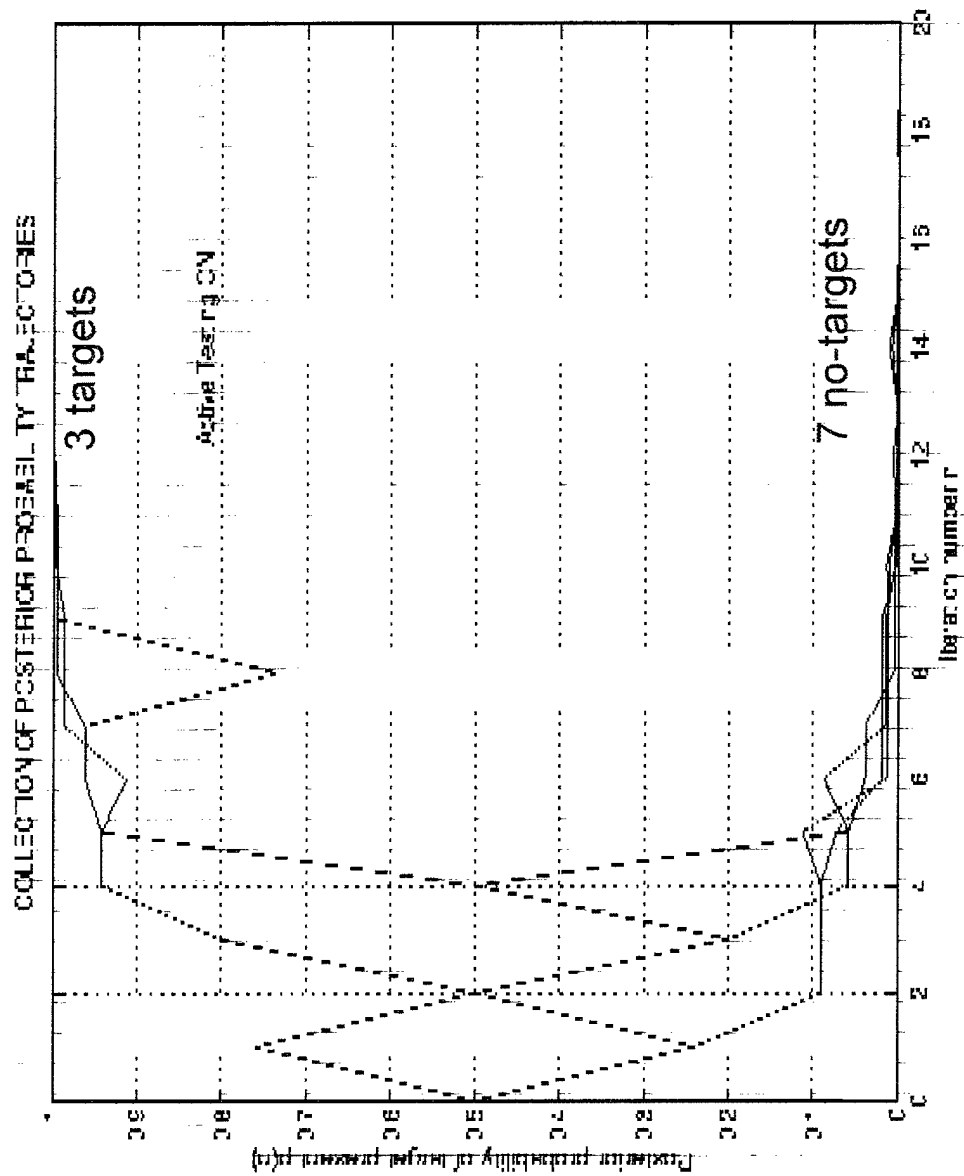Use optimal partition of energy, as previously derived
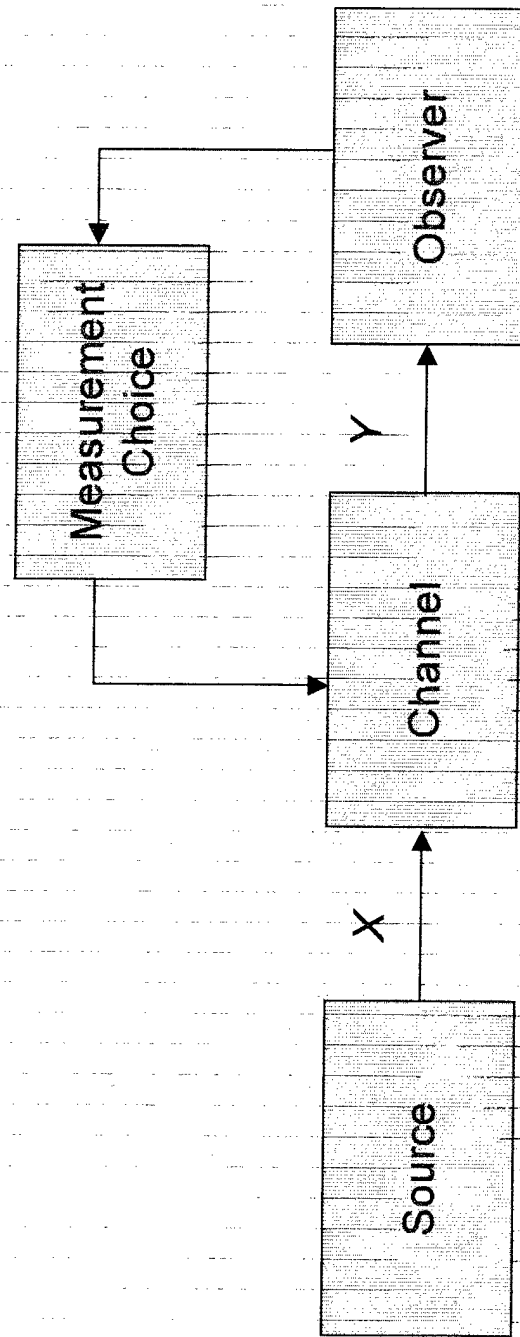
SIMULATION SET-UP

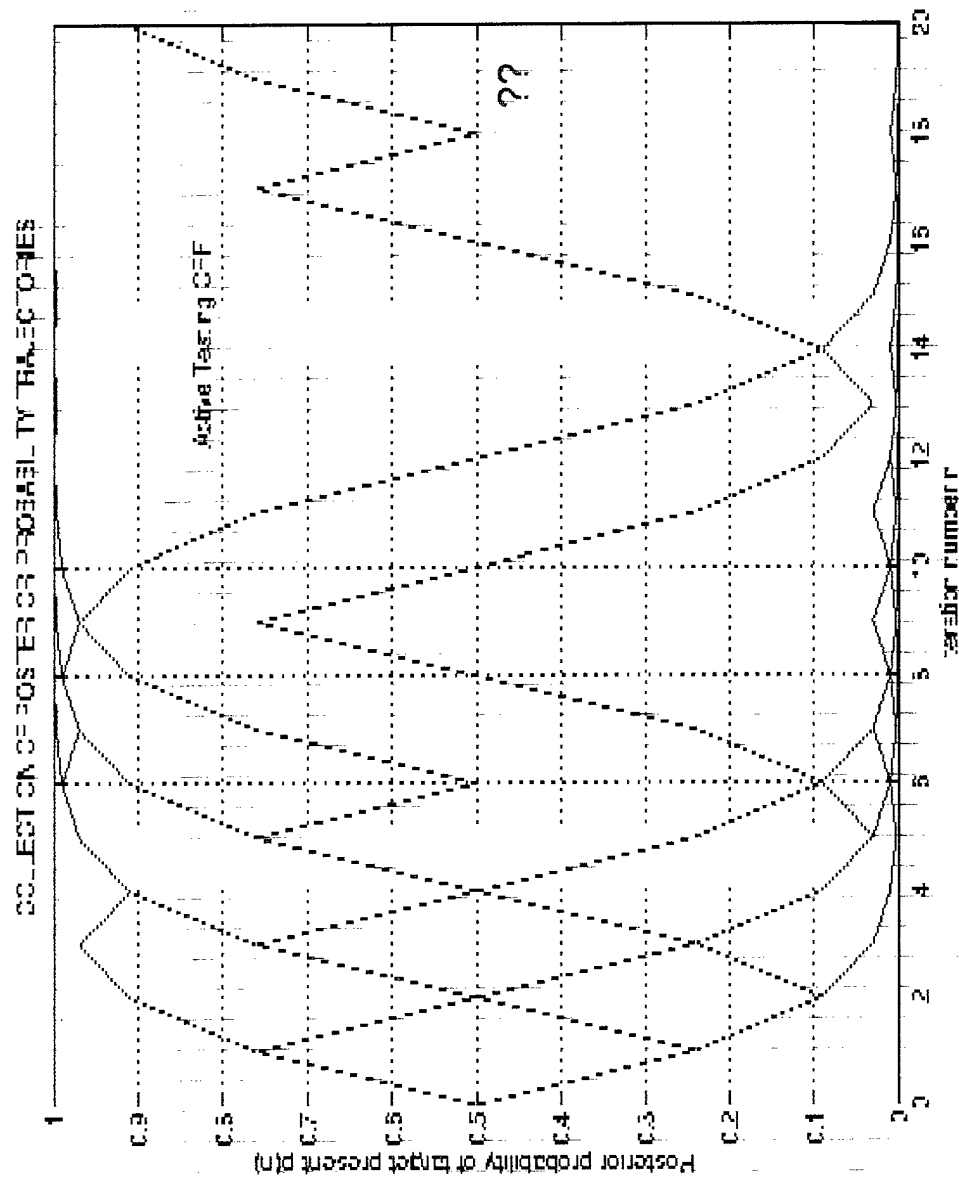

- N = 10 cells

- Total energy E = 5

- 0 dB noise

- Targets in 3 cells
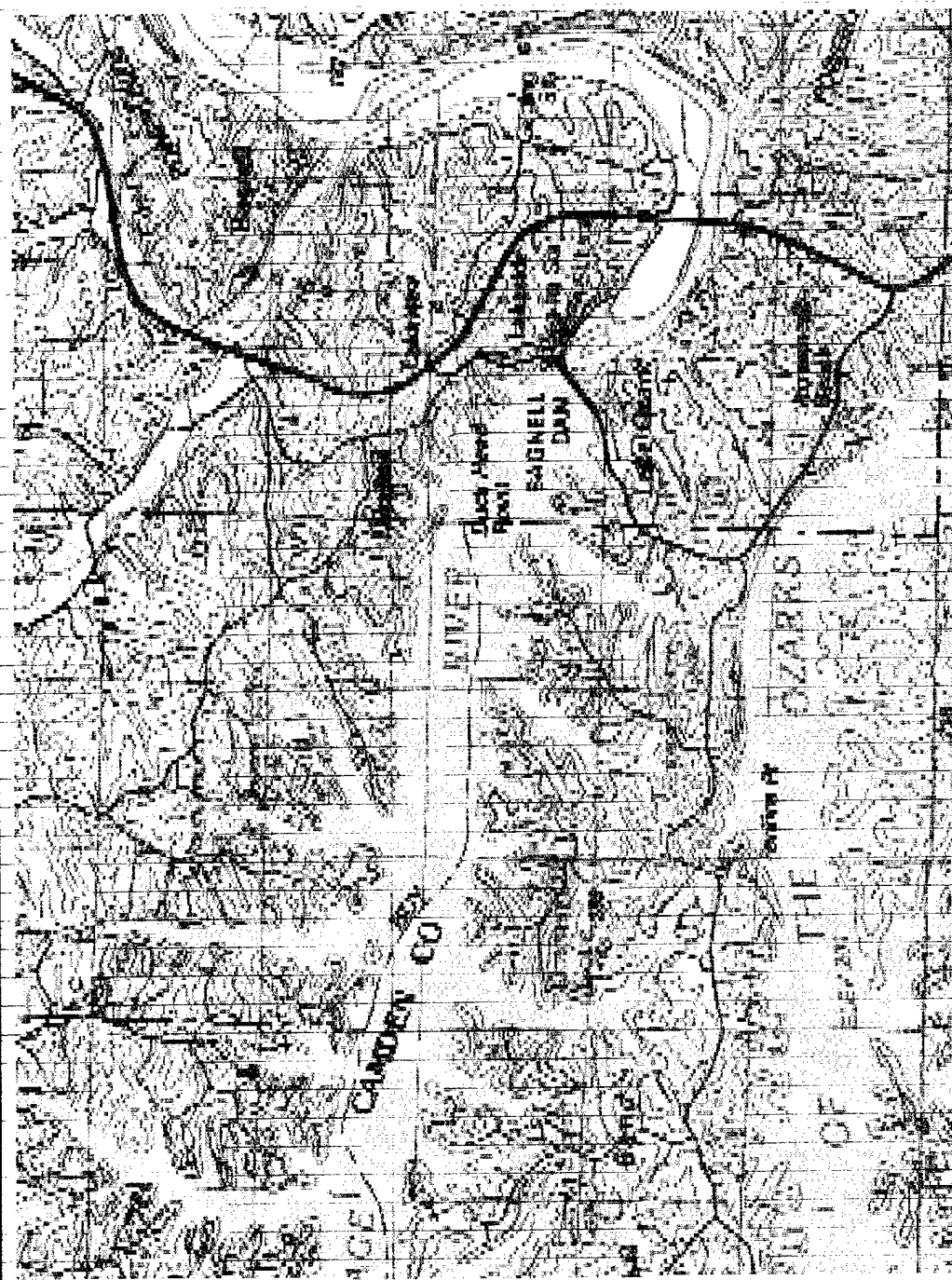
- Prior probability of target present = 0.5, all cells

SEQUENTIAL DETECTION, ACTIVE TESTING ON

COLLECTION OF POSTERIOR PROBABILITY TRAJECTORIES

SEQUENTIAL DETECTION, ACTIVE TESTING OFF

WHERE DO WE GO FROM HERE?

RESEARCH AIM

To investigate the feasibility of active-testing surveillance systems in the context of:

- Airborne multisensor pulse-Doppler surveillance radar

- Ground moving targets (GMTI)

- Multiple targets

- Geographical side information (GIS)

- Platform side information (GPS, INS)

IMMEDIATE GOALS

- Merge terrain-based radar simulation and active testing

- Incorporate linear constraints in illumination patterns (i.e. beamforming)

- Allow different clutter and target signatures in cell (targets are moving

- Include adaptive processing for interference

CONCLUSION

We have:

- introduced the concept of active-testing surveillance systems

- considered multiple-target detection

- derived numerical solution to optimization problem of distribution of finite illumination energy

- shown anecdotal result that active testing improves convergence in sequential detection

- indicated future research directions in airborne multisensor pulse-Doppler surveillance radar